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On the Production of Thermo-electric currents by Percussion.

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THE production of thermo-electric currents by *friction* was observed by P. Erman in 1845,[1] but I do not know that the subject of the present article has ever been examined with any care.

For the purpose of studying the thermo-electric currents produced by percussion, the apparatus represented in the figure
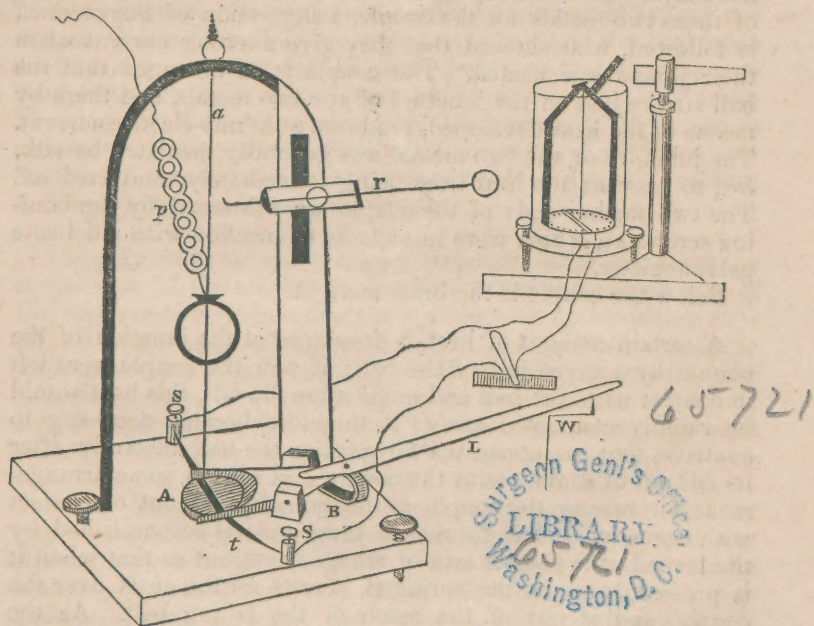
was devised: it consists of a vertical brass wire a, stretched in the manner indicated; on it a brass ball weighing 17 oz. slides freely, the wire passing through one of its diameters. The ball can be raised to the height of from 1 to 5 inches by a string connected with the brass plate p. At the proper moment the ball can be allowed to fall: this is effected by passing the bent end of the rod r through one of the five holes in the brass plate p; by turning this rod through an angle of 90° the ball is set free and falls. The rod is fastened at such a height that when its bent end is in the highest of the five holes, the distance be-

[1] Arch. de l'El., v. 477; Inst. No. 614, p. 355.

tween the lower surface of the ball and the anvil below, is one inch. The holes in brass plate again are exactly one inch apart, so that the experimenter can easily, without altering the apparatus, obtain at will, a fall of 1, 2, 3, 4 or 5 inches successively, by raising the ball by the string, and using in turn each of the five holes in the brass plate. By this means the production of accidental thermo-electric currents from the heat of the hands is avoided, as the string and bent rod enable the observer to make the necessary adjustments from some distance.

The ball falls on a thermo-electric couple *t*, consisting of a compound wire of German silver and iron soldered together, or better, of a compound *plate* of the same metals, the juncture being soldered, as when *plates* are used, the couple suffers but little injury from the repeated falls of the ball. In the selection of these two metals for the couple, a suggestion of Poggendorff is followed, who showed that they give a strong current when their juncture is heated. The couple is so arranged that the ball strikes just on the juncture of the two metals, and there by means of the heat developed, produces a thermo-electric current. The juncture of the two metals was generally insulated by silk, &c., to prevent the heat from being immediately conducted off. The two farther ends of the couple were fastened by the binding screws *s s*, which were in metallic connection with a delicate galvanometer.

Below the couple is the brass anvil A.

A certain amount of heat is developed at the junction of the couple by a given fall of the ball; if now the couple were left in contact with the ball and anvil after the fall, this heat would be rapidly conducted away; it therefore became necessary to contrive, first, an apparatus for raising the ball instantly after its fall out of contact with the couple, and second, some arrangement for raising the couple at the same instant out of contact with the anvil. The former of these ends is accomplished by the lever L, the shorter arm of which is cut out so that when it is pressed down by the spring B, it rests on the anvil over the couple, and is out of the reach of the falling ball. As the sound of the concussion is heard, the long end of the lever is quickly pressed down, and fastened by turning the bent wire at *w*. The lever thus raises the ball $\frac{1}{2}$ inch above the couple, and the latter itself acting at the same instant as a spring, raises itself by its own elasticity above the anvil. The wires from the binding screws were connected with an apparatus for breaking the circuit, in which small cups of mercury were used. This portion of the apparatus was placed on a table; the galvanometer, however, on a shelf attached to the wall of the room with brass nails, it being found that iron nails exercised a considerable effect on the astatic needle. When thus arranged, and

observed with the telescope, the steadiness of the needle was not sensibly affected by a person walking about the room.

The upper needle of the galvanometer was provided with a very fine glass rod, which served as an index, the breadth of the rod being only half of that of the divisions on the galvanometer circle. The end of the glass rod was blackened to render it plainly visible. Directly over the needle, a mirror silvered by Liebig's process was placed at an angle of $45°$; the index was observed with aid of this mirror and a small telescope magnifying five diameters; in this manner $\frac{1}{10}°$ could be estimated.

The falling apparatus was enclosed by wooden screens, also the apparatus for breaking the circuit and the galvanometer. If these precautions are neglected accidental currents are constantly circulating in the wires employed, and no reliable results can be obtained. It is farther necessary after exchanging the couple or handling the binding screws, to allow the apparatus to remain at rest for two or three hours, so that the currents may subside; it is also necessary to select for observation, those intervals of time when the temperature of the room is constant. I may remark, finally, that in spite of all these precautions it is rarely the case that very feeble and nearly constant accidental currents are wholly absent.

The galvanometer was made by Duboscq; after balancing the magnetism of the needles it was found that the copper wire of the coil was so magnetic that the needles took up a position $30°-35°$ on either side of the zero point. I re-wound the frame with American wire, when the needle readily returned to the true zero; upon, however, bringing the two needles very nearly into the same plane, and carrying forward their astasie, the same difficulty was again experienced, when another sample of American wire was tried with a result which was but little better.

All of these samples when tested in the apparatus used for experiments on diamagnetism, were evidently magnetic, the French sample being strongly so. The difficulty was evaded by bending the needles slightly out of the true plane, when they took up a position nearly east and west, and returned with certainty to the true zero. In this state of inferior sensitiveness one simple oscillation consumed 18 seconds. There were sufficient indications to show that owing to the magnetism of the coil the needle was more sensitive to currents when standing at $10°-15°$ than when at $0°$; it accordingly became necessary to calibrate the instrument with care. This was done by one of the methods described by Melloni and quoted by Tyndall, (Heat considered as a mode of motion, p. 370).

For degrees under $10°$ the constant currents employed in the calibration were produced by a small thermo-electric pile with one of its faces turned toward the exterior colder wall of the

room, while the other face was directed toward an interior wall. These, as it were natural sources of heat gave very constant currents, and by partially closing one of the caps of the pile, any desired deviation between 0° and 10° could readily be obtained.

It was found that for about 6° the deviation of the needle was directly proportional to the strength of the current; for degrees beyond this, it was necessary to construct a curve embodying the corrections obtained experimentally. The ratio between the first and final deviation up to 30° was also obtained; it was constant for 6°. These latter determinations were important, as after the first deviation the needle, owing to conduction in the couple, slowly sinks to 0°, and only then comes to rest. I was not able to measure with exactitude the time required for currents produced by falls of the ball from different distances to subside, the imperfect results obtained showed that it varied between $1\frac{1}{2}$ minutes up to $3\frac{1}{2}$ minutes, according to the distance fallen by the ball. It having been found then in the calibration experiments, that the force of the current was proportional to the deviation up to 6°, and farther, that the first deviation was proportional to the final deviation for the same number of degrees, in the results given below, where the first deviation was below 6°, the observations actually obtained and unreduced will be given, but where the first deviation exceeded 6° the reduced results will be found.

As the total amount of heat produced by the fall of a body is divided between the falling body and that arresting its motion, it is evident that if the mass of the latter be small compared with that of the falling body, its *temperature* will, owing to this fact, be correspondingly high; and if the arresting body be a thermo-electric element of small mass, a proportionately large deviation of the galvanometer needle will be produced. If, however, the couple at the moment of the percussion and afterwards, be allowed to be in metallic contact with the metallic ball, the temperature of the couple will by conduction be rapidly reduced to that of the metallic ball, so that the deviation of the needle will be very small, and the phenomena complicated. To illustrate this I give, in table 1, the small and irregular deviations which were produced under these circumstances; the ball, couple, and anvil all remaining in metallic contact after the fall.

TABLE 1.

Distance fallen,	1 in.	2 in.	3 in.	4 in.	5 in.
Deviations,	$\frac{2}{10}°$	$\frac{2}{10}°$	$\frac{3}{10}°$	$\frac{7}{10}°$	$\frac{4}{10}°$
	$\frac{1}{10}$	$\frac{2}{10}$	$\frac{3}{10}$	$\frac{3}{10}$	$\frac{5}{10}$
	0	0	$\frac{1}{10}$	$\frac{2}{10}$	0

In table 1, a newly prepared compound plate similar to that used in table 4 was employed.

To avoid the effects of conduction external to the couple, a number of insulating substances were tried, which gave more or less constant results.

1. Thin card board or plates of mica placed above and below the couple gave irregular results.

2. Two thicknesses of dried bladder, placed above and below the couple, gave somewhat better results.

3. Four thicknesses of heavy woven silk were also used for the same purpose.

4. The best results were, however, obtained by using heavy woven silk, which was spread over with a coating of yellow wax, and then wrapt around the couple at the juncture. This insulating substance after being used for some time so as to become compacted, gave results which were about as constant as could be expected under the circumstances.

Below are results obtained in these several ways:

TABLE 2.— *With two skins above and below.*

Distance fallen,	1 in.	2 in.	3 in.	4 in.
	$1\cdot5^\circ$	$2\cdot2^\circ$	$3\cdot0^\circ$	$5\cdot8^\circ$
	$1\cdot4$	$2\cdot3$	$4\cdot3$	$4\cdot1$
	$1\cdot8$	$2\cdot5$	$3\cdot0$	$4\cdot4$
First unreduced	$1\cdot2$	$3\cdot5$	$3\cdot4$	$5\cdot9$
deviations,	$1\cdot4$	$3\cdot0$	$3\cdot5$	$6\cdot0$
	$1\cdot2$	$3\cdot5$	$3\cdot7$	$5\cdot0$
	$1\cdot1$	$2\cdot4$	$4\cdot1$	$5\cdot8$
	$1\cdot1$	$2\cdot2$	$3\cdot4$	$4\cdot9$
Average,	$1\cdot3$	$2\cdot7$	$3\cdot55$	$5\cdot2$

In this and in all the other tables, the order of the experiments was across the page, from left to right, and not down the single columns.

Table No. 3, contains results obtained with four layers of plain silk above and below the couple.

TABLE 3.

Distances fallen,	1 in.	2 in.	3 in.	4 in.
	$1\cdot6^\circ$	$3\cdot4^\circ$	$3\cdot7^\circ$	$6\cdot1^\circ$
	$1\cdot4$	$2\cdot7$	$3\cdot9$	$5\cdot4$
	$1\cdot6$	$3\cdot5$	$4\cdot1$	$6\cdot0$
First unreduced	$1\cdot7$	$2\cdot7$	$4\cdot2$	$6\cdot0$
deviations,	$1\cdot5$	$2\cdot6$	$4\cdot3$	$6\cdot0$
	$1\cdot5$	$2\cdot8$	$5\cdot0$	$6\cdot5$
	$1\cdot4$	$2\cdot6$	$4\cdot7$	$6\cdot0$
	$1\cdot4$	$2\cdot6$	$4\cdot3$	6.9
Average,	$1\cdot5$	$3\cdot0$	$4\cdot5$	$6\cdot0$

The results given in tables 2 and 3, were obtained by using a compound *wire* of German silver and iron with a diameter of 9 of a millimeter; the juncture was bound with a little fine iron wire and soldered. This form of couple was found to lose its shape by the repeated blows; it also finally cut the insulating substance, so that in all the following experiments *plates* of the

same metals soldered together were used; the form of these plates remained nearly unaltered.

Accordingly, to obtain the results given in 4 and 5, a compound plate of this kind was used; the breadth of the plate was 7 millimeters, length 150 millimeters, thickness of iron and of German silver being about ·2 of a millimeter.

The plate in table 4 was wound with four layers of heavy plain silk.

TABLE 4.

Distance fallen,	1 in.	2 in.	3 in.	4 in.	5 in.
	1·6°	2 6°	3·8°	4·0°	4·9°
First unreduced	1·4	2·3	3·4	3·9	4·6
deviations,	1·3	2·2	3·1	3·9	4·7
	1·3	2·4	3·4	4·0	4 5
	1·3	2·2	3·5	3·8	4·5
Average,	1·38	2 3	3·4	3·7	4·6

Table 5 gives results when 4 layers of *waxed* silk were used with the same couple.

TABLE 5.

Distance fallen,	1 in.	2 in.	3 in.	4 in.	5 in.
	1·5°	3·1°	5·0°	6·4°	8 9°
First unreduced	1·5	3·0	4·8	6·3	8·7
deviations,	1·6	2·9	4·8	6·2	8·2
	1·5	2·9	4·2	5·6	8·3
	1·4	2·8	4·2	5·7	8·0
Average,	1·5	2·94	4·6	6·04	8·4
Reduced average,	1·07	2·1	3·28	4·3	6·0

It will be observed that in tables 2, 3 and 5 the result is more or less perfectly indicated that the force of the current is proportional to the distance the ball falls through, or in other words to the square of its velocity at the moment of impact.

Effect of allowing the ball to remain in contact with insulated couple after the impact.

The results given in table 6 were obtained directly after those given in table 5, everything remaining unaltered except that the ball was not raised out of contact with the couple.

TABLE 6.

Distance fallen,	1 in.	2 in.	3 in.	4 in.	5 in.
	2·0°	2·5°	3 6°	4·2°	5·8°
First unreduced	1·9	2·6	3·1	4·0	5·7
deviation,	1·7	2·3	3·2	4·0	5·4
	1 6	2·3	3·0	3·6	5·1
Average,	1·8	2·42	3·22	3·95	5·5

The extent to which the heat generated is thus conducted away from the couple is very noticeable in the last three columns, but it is a little remarkable that the deviations in the first column are higher than in table 5; a corresponding result obtained

with a *narrow* couple is given below in table 8. To ascertain that the plate had not been altered, experiments were made with it afterward, the ball being lifted.

To find out whether any peculiar influence was exercised by the mass of the couple within small limits, the above mentioned plate was now cut down, till its breadth was 3 millimeters. It was covered with waxed silk and the following results obtained:

TABLE 7.

Distance fallen,	1 in.	2 in.	3 in.	4 in.	5 in.
Reduced deviations,	1·50°	3 28°	4·80°	6·46°	7·20°
	1·35	2·42	4·77	6·10	7·10
	1·20	2·42	3 50	4·90	6·38
	1·14	2·07	3 00	5·00	7·00
	1·07	2·01	3·00	4·90	6·46
	1·14	1·90	3·20	5·00	6·20
Average,	1·23	2·35	3·71	5·39	6·72

To compare the temperature here developed with what was produced in the broad plate before it was cut down, I give below the reduced deviation of the broad plate taken from table 5 :

	1 in.	2 in.	3 in.	4 in.
Reduced deviation of narrow plate,	1·23	2·35	3·71	5·39
" " " broad "	1·07	2·1	3·28	4·30
Difference,	·16	·25	·43	1·09

The narrow plate used in table 7 being employed and arranged exactly as before, the ball was allowed after its fall to remain in contact with the insulated couple.

TABLE 8.

Distance fallen,	1 in.	2 in.	3 in.	4 in.	5 in.
Unreduced deviations,	2·4°	3·0°	3·7°	3·9°	5·6°
	2·5	3·1	3·8	3·9	5·9
	2·5	3·0	3·4	3·5	5·2
	2·6	3·1	3·7	3·9	5·9
Average,	2·5	3·05	3·6	3·8	5·65
Reduced average,	1·79	2·17	2·57	2·7	4·0

Effect of the first twenty, &c. falls on the newly prepared plate.

When the couple is wound with plain or with waxed silk, and subjected to the action of the falling body, the first 15–20 deviations of the needle are much larger than any above given with the successive falls as the silk becomes compacted, the deviations decrease in size, reach a minimum, and remain about as constant as shown in the tables. The results so far given then, except, of course, in case of table 1, were obtained after this point had been approximately reached. I give below, as a sample, the first set of deviations obtained directly after winding with waxed silk the couple used in table 7. The ball was lifted in the usual way.

Distance fallen being 5 in., the reduced deviations are given, 23·5°, 17·2°, 16·3°, 13·8°, 12·4°, 11·6°, 10·1°, 8·5°, 9·1°, 9·1°, 8·6°: 8·4°, 8·1°, 7·9°, 8·4°, 8·4°, 7·85°, 7·4°, 7·5°, 6·6°, 7·2°, 7°, 6·8°.

A similar action was observed with unwaxed silk. This might be accounted for by saying that the mass of silk and wax becoming compacted is then a better conductor of heat than before, and that the temperature of the couple is thus lowered by the short but necessary contact with the ball; but the comparatively small effect which is produced even by continued contact with the ball shown in tables 6 and 8 prove that this supposition is untenable.

The larger deviation must then be attributed to the sliding of the particles of silk and wax over themselves, this taking place to a much greater extent in the first twenty falls than afterward. After the minimum point has been reached, if the couple is laid bare and rewound, the same large deviations are obtained, showing that they are not due to an alteration in the couple itself.

Finally, it is remarkable that a much smaller mechanical force applied directly to the couple in the shape of friction, produces a disproportionately large deviation; thus drawing the wooden end of a lead-pencil once over the naked junction with a force less than would be generated by the ball falling 1 inch gave a deviation of 18–25°.

It is hardly necessary to add, that the deviation of the needle was in all cases in the same direction as though heat had been applied to the juncture of the thermo-electric couple.

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